Photochromism

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Encoding Optical Signals**

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In the information age, a large volume of data is transmitted, computed, and displayed every day. These data typically come in two formats: electronic signals and optical pulses. Both have advantages and disadvantages, and therefore, current devices use electrical and optical formats side by side. Such signals are frequently converted from one format into another, or from one type into another. It has now been shown that lasers can be used to encode binary digital light pulses. Obviously, it is desirable to directly transmit information in one light ray to another light ray without converting it back to the electronic format. To accomplish such a difficult task, optically active materials are required.

Traditionally, light rays are mixed through an optical medium with high nonlinear effects, and the use of optical communication is driven by the fact that enormous quantities of data can be transmitted over long distances in optical fibers. For instance, electro-optical modulators are used to encode optical signals from electrical signals. The bottleneck in using nonlinear optical materials is that the materials must be non-centrosymmetric for second-order effects. Out of a myriad of available materials, only a handful can be fabricated into working devices, such as the modulators that are based on $LiNbO_3$ crystals and that have been widely used in telecommunications.[1] These inorganic $LiNbO_3$ crystal modulators use a second-order nonlinear effect, namely the electro-optic effect, $\chi^{(2)}$, to control the on/off switching of light. These analyses reveal two fundamental challenges in using nonlinear optical materials: 1) Nonlinear effects are inherently much smaller than linear effects, and 2) highly polar materials are intrinsically unstable, thus limiting the ceiling of nonlinearity. Recently, Zhu, Li, and co-workers have presented a change from nonlinear optical materials to linear photoswitching materials, while also accomplishing modulation effects.[2]

Up to now, there has been little effort in developing optical materials that perform photo-optical modulations or devices that convert optical signals at one wavelength into optical signals at other wavelengths. A collaboration between the groups of Zhu and Li has led to a new concept to address this problem. Together, they demonstrated that the quantitative photoswitching of a di(bisthiazolyl)ethene ($\mathbf{1_O}$; Figure 1)

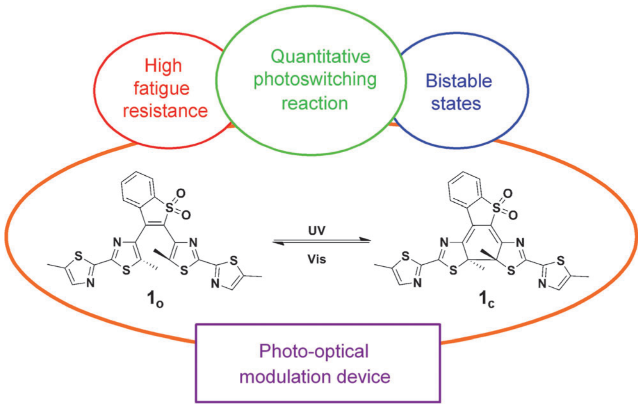

Figure 1. The photochromic system $\mathbf{1_O}/\mathbf{1_C}$ is characterized by a notable collection of desirable properties: excellent fatigue resistance, high thermal stability, and quantitative photoswitching.

has photo-optical modulation properties and can successfully convert continuous waves into meaningful light pulses. Their report serves as a proof of concept for the replacement of nonlinear optical materials by photoswitchable molecules for light modulation. Furthermore, the usage of linear optical properties obviates the need for high-power lasers to achieve nonlinear effects.

Photoswitchable molecules are key to accomplishing such challenging tasks. Most current photoswitchable molecules do not display quantitative reversible switching; the reported photochromic system $\mathbf{1_O}/\mathbf{1_C}$, however, is characterized by excellent fatigue resistance and high thermal stability, which addresses this issue. The quantitative photo-reversibility that is displayed by this system enables the use of one light ray to control another light ray traveling through the photoswitchable medium. Therefore, one light ray can transfer the information within it to another light ray, so that all optical modulations can be achieved using linear optical effects rather than nonlinear optical effects.

In the experiment designed by Zhu, Li, and co-workers, the first light ray consisted of two lasers at 561 and 375 nm, and the second beam was white light. The 375 nm laser caused ring closure of $\mathbf{1_O}$, which switched on the absorption and

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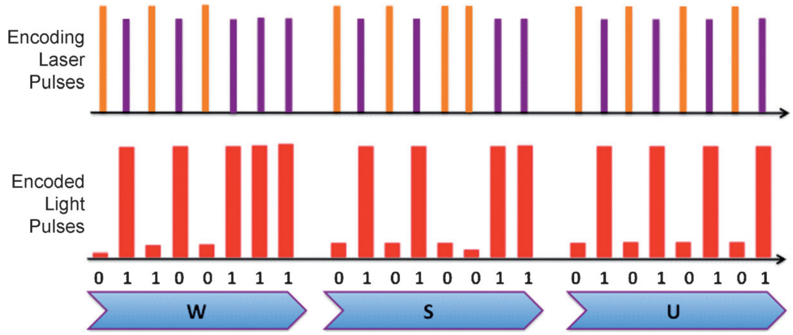

Figure 2. Laser pulses were used to photoswitch the medium that contains **1** to encode "WSU". In this arrangement, 561 nm light (orange) encodes "0", whereas 375 nm light (purple) encodes "1". Ring opening of $\mathbf{1_C}$ and ring closure of $\mathbf{1_O}$ cause the medium to switch between opaque and transparent states, which leads to the output of the eight-bit ASCII characters that correspond to "WSU".

encoded the binary information "1" into the absorbance unit. On the other hand, irradiation with the 561 nm laser led to ring opening, which switched off the absorbance and encoded a binary information of "0". When these two lasers operate according to the standard eight-bit ASCII characters, meaningful information that can be understood by humans emerges. Figure 2 depicts how these two lasers transmit the word "WSU" to the white-light beam through the photoswitching molecules. The letter U corresponds to 01010101 in eight-digit binary code; thus it requires a pulse sequence of alternating the 571 nm and 375 nm lasers. Every letter can be encoded in a similar fashion and launched into the optical fiber for telecommunication. Figure 2 shows how the abbreviation "WSU" is encoded by two lasers and subsequently sent through an optical fiber to the reading devices.

Molecular-logic-based light encoding or computation is a relatively young field but mature enough for its story to be told, which highlights the connection among information technology, materials science, and chemistry.[3,4] The photochromic bistable bis(aryl)ethenes can be photo-interconverted between ring-opened and ring-closed forms. However, at the moment, in contrast to the detailed study of this process in solution,[5,6] the application of these compounds as films in practical devices has been less studied. Notably, by providing a route towards all-solid-state systems for fabricating a layer of logic,[7] this experiment demonstrates that nonmodulated light can be encoded by another orthogonal light beam, realizing a photo-optical modulation that is similar to the known electro-optical modulation. Indeed, there are more than 348 codes imparted by the photoswitching that correspond to the transmitted information. Also, the photo-optical modulation can reach 50 GHz, which is fast enough for potential applications in information communication. Moreover, the excellent fatigue resistance and the quantitative photo-reversibility are crucial. For a light-modulation device, the limited time exposure can guarantee the efficient photoswitching between the two states (photochemical conversion to the ring-closed state is nearly quantitative, and the conversion for the reverse photochemical ring-opening process is $\geq 80\%$).

Zhu, Li, and co-workers have thus shown that the information encoded in a light beam can be faithfully transferred to a white-light beam without a single error. As demonstrated for the encoding of optical signals, a new strategy for the modulation of light with encoded information emerges, which uses fundamental properties of molecular photoswitches. Therefore, classical chemistry can stimulate ingenuity in the bottom-up approach to information science and nanotechnology.[8,9]

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